Indian J. Phys. **70A** (4), 517–522 (1996)

IJP A
— an international journal

Anomalous conversion of high multipole transitions-penetration effects

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Received 21 August 1995, accepted 14 December 1995

Abstract : Penetration parameters are calculated for some high multipole transitions ($M3$, $M4$) using the data available in literature. The finite values of penetration coefficients suggest that as in the case of $M1$ transitions, for high multipole transitions the existing anomalies can be explained in terms of penetration effects.

Keywords : Internal conversion data, high multipole transitions, penetration effects

PACS No. : 23.20.Nx

1. Introduction

Accurate measurement of the internal conversion coefficients is of importance in assigning the multipolarity of gamma transitions. Also, accurate experimental data is necessary to test the theoretical predictions made by several authors. The use of high resolution solid state detectors in nuclear research facilitates to measure the conversion coefficients of low and high multipole gamma transitions accurately.

In the survey of literature, it is found that the absolute as well as relative conversion coefficients are measured very accurately. The experimental conversion coefficients of $E2$ transition are in good agreement with the theoretical values. On the other hand, some anomalies are observed in the case of $M1$ transitions. There is quite disagreement between experimental and theoretical conversion coefficients of $M1$ transitions. The disagreement between the theoretical and experimental conversion coefficients can be interpreted in two ways. The first possibility is to consider the admixture of higher multipole moments, such as, $M1 + E2$ type. Where such an admixture is not possible, these deviations can be explained in terms of the penetration effects, proposed by Church and Wenser [1]. Due to the finite size of the nucleus, there is a finite probability for the conversion electrons to interact with the nuclear field, thereby the conversion matrix elements are modified by penetration matrix elements. Study of these penetration effects yields valuable information regarding nuclear structure.

In general, if theoretical values are not in agreement with experimental values, one can suspect the theoretical calculations. Regarding the internal conversion coefficients, so far several theories are developed. The different theoretical calculations are available in the literature [2–5]. All the above theories, can explain the $E2$ values very accurately. In view of the above agreement in $E2$ conversion coefficients, there is no possibility of suspecting the theoretical computations.

In the case of high multipole transitions, such as $E3$, $M3$, $E4$, $M4$ *etc.*, some discrepancies between theory and experiment have been pointed out by Ranon *et al* [6] They surveyed the most accurate experimental conversion coefficients of high multipole transitions and compared them with the theoretical values of [4]. They pointed out that the experimental values are consistently lower than the theoretical values. Later on Campbell and Martin [7] measured such conversion coefficients of high multipole transitions very accurately and pointed out the same discrepancies. Several authors attempted this programme and confirmed that the experimental conversion coefficients of high multipole transitions are lower than the theoretical values. Since the experimental values are lower than the theoretical values, there is no possibility of assuming admixture of higher multipoles. Hence, these deviations can possibly be explained in terms of the penetration effects. In the present paper, the penetration effects are calculated for different high multipole transitions and the results are discussed.

2. Method of analysis

Accurate experimental conversion coefficients of some high multipole transitions ($M3$, $M4$) are taken from the literature [6–11]. The corresponding references are given in Table 1.

The penetration coefficients have been calculated using the formula [12] given below

$$\alpha_k(\mathrm{Th}) = \alpha_k(\mathrm{Expt.})\left(1 + B1\,\lambda + B2\,\lambda^2\right).$$

In the formula α_k (Expt.), α_k (Th) represent the experimental and the theoretical conversion coefficients respectively. $B1$ and $B2$ are penetration coefficients and they are interpolated at the required energies from the Tables of ref. [12]. The theoretical conversion coefficients are also interpolated for the required energies from the Tables of ref. [4]. The data has been interpolated using a 'spline interpolation programme'. Using the above formula, λ-the penetration parameters are evaluated for different transitions. The results thus obtained are given in the Table 2.

Table 1. The experimental and theoretical α_K and α_T values of different transitions.

Isotope	Energy (KeV)	Experimental (α_K)	Experimental (α_T)	References	Theoretical (α_K)	Theoretical (α_T)
$^{197m}Hg_{00}$	165 ($M4$)	47 ± 12	274.8 ± 19.2	S Bhuloka Reddy *et al* [8]	76.944	332.94
$^{94m}Nb_{41}$	41 ($M3$)	710 ± 37	1321.2	Ch. Suryanarayana *et al* [10]	773.38	1384.7
$^{91m}Nb_{41}$	104.5 ($M4$)	115 ± 5	173.87	V Laxminarayana *et al* [11]	117	175.87
$^{125m}Te_{52}$	109 ($M4$)	151 ± 11	334.64	S Bhuloka Reddy *et al* [8]	190.7	374.34
$^{87}Sr_{30}$	388.4 ($M4$)	0.177 ± 0.006	0.212 ± 0.002	J L Campbell and Martin [7]	0.181	0.218
$^{113}In_{49}$	391.7 ($M4$)	0.441 ± 0.013	0.540 ± 0.007	J L Campbell and Martin [7]	0.444	0.557
$^{115}In_{49}$	336.3 ($M4$)	0.83 ± 0.03	1.673 ± 0.014	J L Campbell and Martin [7]	0.854	1.094
$^{131}Xe_{54}$	163.9 ($M4$)	30.1 ± 0.6	30.51	J L Campbell and Martin [7]	31.35	31.76
$^{137}Ba_{56}$	661.63 ($M4$)	0.0894 ± 0.001	0.1121	J L Campbell and Martin [7]	0.0915	0.114
$^{139}Ce_{58}$	754 ($M4$)	0.078 ± 0.004	0.0937	D Sudhkar Reddy *et al* [9]	0.0666	0.0817

Table 2. The penetration parameters (λ), experimental and theoretical transition probability (T) and hindrance factors for various transitions

Isotope	Energy (KeV)	λ (α_K)	λ (α_T)	T (Exp)	T (Theory)	Hindrance
$^{97m}Hg_{80}$	165 ($M4$)	22.87 ± 11	7.59 ± 3	2.908×10^{-8}	1.688×10^{-7}	5.806
$^{4m}Nb_{41}$	41 ($M3$)	14.30 ± 9	7.70	1.388×10^{-6}	7.2×10^{-7}	0.5184
$^{1m}Nb_{41}$	104.5 ($M4$)	2.90 ± 1.8	1.919	1.05×10^{-5}	5.90×10^{-10}	5.62×10^{-5}
$^{25m}Te_{52}$	109 ($M4$)	26.90 ± 11	12.14	4.12×10^{-10}	1.62×10^{-9}	3.953
$^{7}Sr_{38}$	388.4 ($M4$)	4.51 ± 2	5.46 ± 2	5.61×10^{-5}	7.31×10^{-5}	1.302
$^{13m}In_{49}$	391.7 ($M4$)	2.58 ± 1.7	3.7 ± 1.5	7.515×10^{-5}	1.33×10^{-4}	1.770

Table 2. *(Cont'd.)*

Isotope	Energy (KeV)	λ (α_K)	λ (α_T)	T (Exp)	T (Theory)	Hindrance
$^{115}In_{49}$	336.3 ($M4$)	3.39 ± 2.5	2.3 ± 1.3	1.600×10^{-5}	1.377×10^{-4}	8.609
$^{131}Xe_{54}$	163.9 ($M4$)	3.76 ± 1.7	3.86	2.157×10^{-8}	7.031×10^{-8}	3.259
$^{137}Ba_{56}$	661.6 ($M4$)	2 ± 1.5	1.60	0.004	0.021	5.832
$^{139m}Ce_{58}$	754 ($M4$)	$11\ 6 \pm 3.1$	10.16	0.0117	0.0730	6.225

The experimental transition probabilities are calculated using the formula

$$T(\text{Expt.}) = \frac{0.693}{T_{1/2}(1 + \alpha_T)}.$$

The life times are taken from Table of isotopes [13]. In the above calculation, where the experimental total conversion coefficients are not available, theoretical values are adopted. The corresponding estimates [14] are calculated using the formula given below,

$$M3 = 8.7 \times 10^{1} \cdot A^{4/3} \cdot E_\gamma^7 \cdot S,$$

$$M4 = 4.8 \times 10^{-5} \cdot A^2 \cdot E_\gamma^9 \cdot S.$$

In the above formulae, A is mass number, E_γ is energy in MeV and S is spectroscopic factor. Here the value of S is taken as 1. The theoretical transition probabilities thus obtained are also furnished in the Table 2. Using the transition probabilities, the corresponding Hindrance factors are estimated and given in the same Table.

The percentage deviations of theoretical conversion coefficients from experimental values are calculated and are shown in the Figure 1.

3. Results and discussion

From the Table 2, it can be seen that the penetration parameters obtained are of considerable size. The magnitudes of the penetration parameters indicate the extent of deviation between theoretical and experimental conversion coefficients.

The conversion coefficients of high multipole transitions as furnished in the Table 1, which indicate that the experimental values are lower than the theoretical values. Hence, there is no possibility of assuming admixture due to higher multipoles. Hence, one can suspect the theoretical tabulations, but as mentioned above since there is good agreement between experimental and theoretical conversion coefficients of $E2$ transitions, doubts in the configuration of the theoretical values can be ruled out.

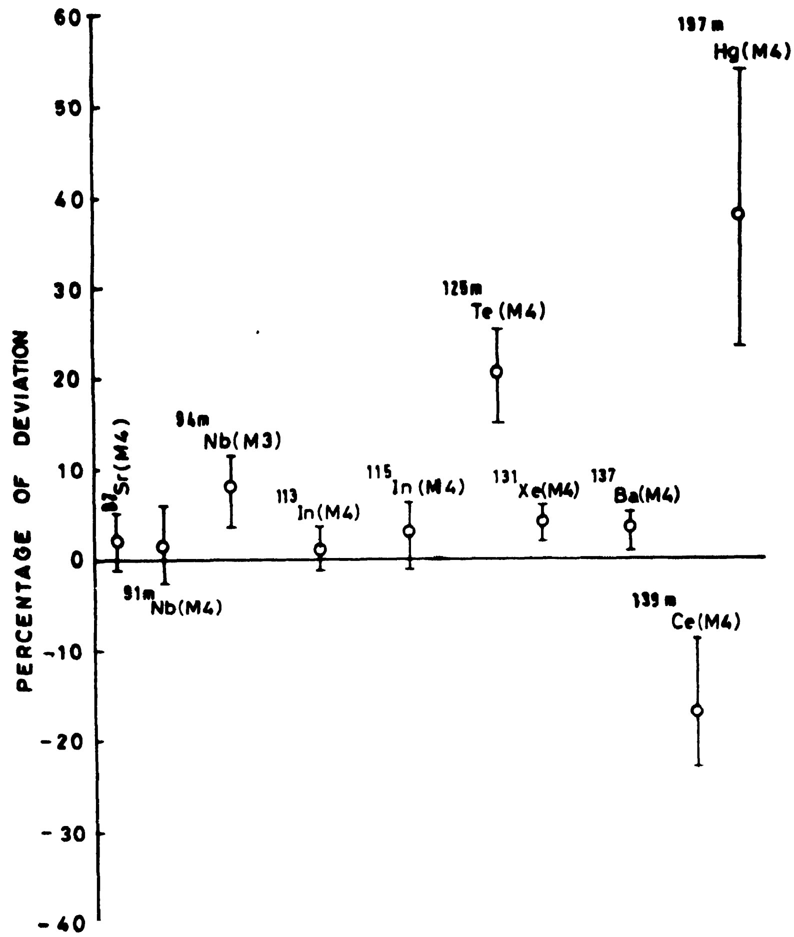

Figure 1. Deviations of theoretical conversion coefficients from the corresponding experimental values of various transitions.

In view of the above facts, the only way of explaining the deviation between theoretical and experimental values, is to consider the penetration effects. Therefore, it is concluded that the anomalies in the conversion data for the high multipole transitions can be interpreted in the frame work of penetration effects, as in the case of *l*-forbidden hindered *M*1 transitions.

4. Conclusion

The anomalies in the conversion of high multipole transition can be possibly explained in the frame work of penetration effects.

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